Novel Nanolaminates for Aerospace Applications

Dr. Martin Volz, NASA Marshall Space Flight Center
Dr. Consty Mazuruk, University of Alabama in Huntsville

Nanolaminate manufacturing (NLM) is a new way of developing materials whose properties can far exceed those of homogeneous materials. Traditional alloys, composites and bulk laminates tend to average the properties of the materials from which they were made. With nanostructured materials, the high density of interfaces between dissimilar materials results in novel material properties. For example, materials made from alternating nanoscale layers of metals and oxides have exhibited thermal conductivities far below those of the oxides themselves. Also, metallic nanolaminates can have peak strengths 100 times larger than the bulk constituent metals. Recent work at MSFC has focused on the development of nickel/aluminum oxide (Ni/Al_2O_3) nanolaminates. Ni/Al_2O_3 nanolaminates are expected to have better strength, creep and fatigue resistance, oxygen compatibility, and corrosion resistance than the traditional metal-matrix composites of this material, which has been used in a variety of aerospace applications. A chemical vapor deposition (CVD) system has been developed and optimized for the deposition of nanolaminates. Nanolaminates with layer thicknesses between 10 and 300 nm have been successfully grown and characterization has included scanning electron microscopy (SEM) and atomic force microscopy (AFM).

Nanolaminates have a large variety of potential applications. They can be tailored to have both very small and anisotropic thermal conductivities and are promising as thermal coatings for both rocket engine components and aerobraking structures. They also have the potential to be used in aerospace applications where strength at high temperatures, corrosion resistance or resistance to hydrogen embrittlement is important. Both CVD and magnetron sputtering facilities are available for the deposition of nanolayered materials. Characterization equipment includes SEM, AFM, X-ray diffraction, transmission electron microscopy, optical profilometry, and mechanical tensile pull testing.

Novel Nanolaminates for Aerospace Applications

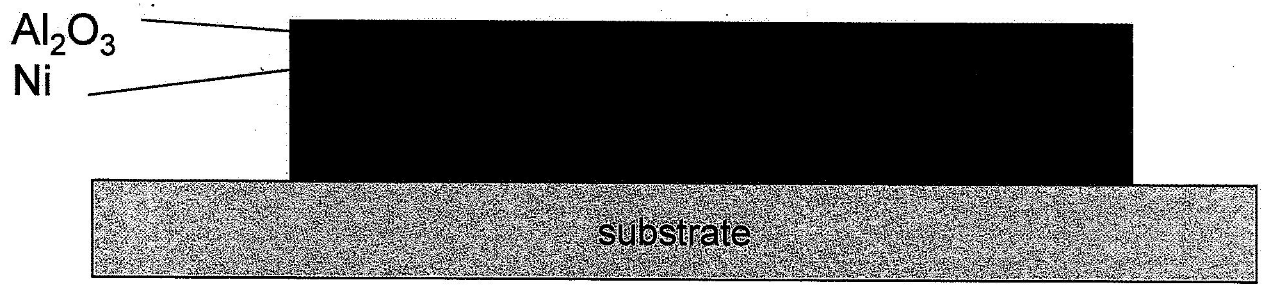
Dr. Martin P. Volz
NASA Marshall Space Flight Center
EM30
Huntsville, AL 35803

Dr. Konstantin Mazuruk
University of Alabama in Huntsville
Huntsville, AL 35899

Outline

- Nanolaminate properties
- Applications
- Current (Advanced Materials for Exploration) nanolaminate project at MSFC and UAH
- Nano-engineering capabilities and facilities at MSFC and UAH

What is a Nanolaminate?



- A nanolaminate is a layered structure with layer thickness between a few nanometers to 10's of nanometers

- Potential materials include metals, oxides and semiconductors

- Structures can be made from similar materials (e.g. Cu/Ni) or dissimiliar materials (W/Al_2O_3)

- The nanolaminate can consist of hundreds or thousands of individual layers

- Nanolaminates can be used as coatings or stand-alone structures

Novel Nanolaminate Properties

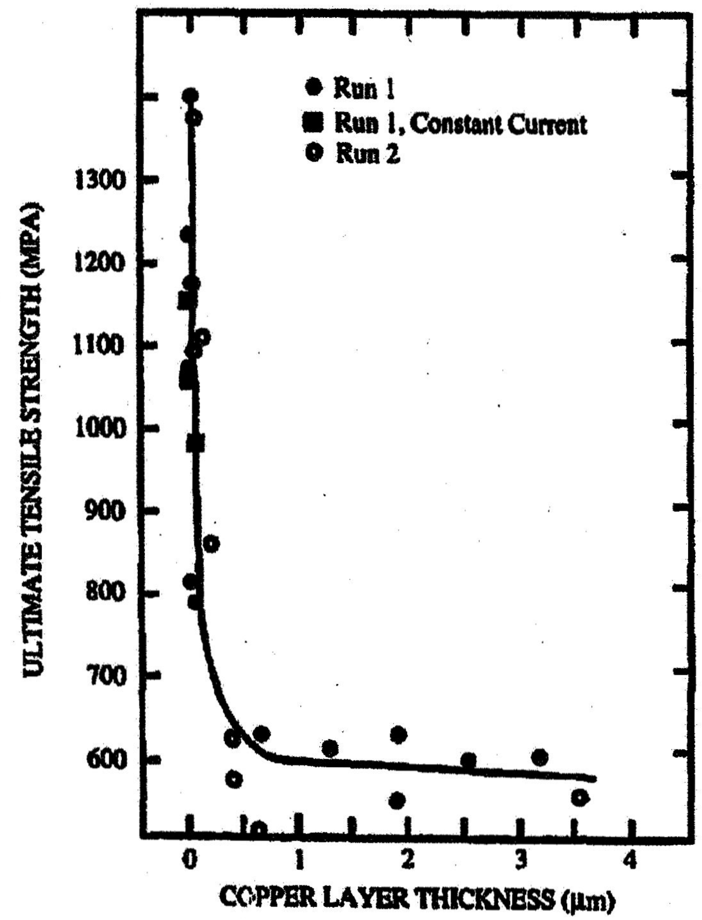
- Traditional composites and alloys follow the "rule of mixtures", where the properties of the combined material are the average of the constituent materials

- Nanolaminate properties can surpass those expected from the "rule of mixtures"

- Nanolaminate properties are determined by the thickness and detailed structure of the interfaces

Increased Strength

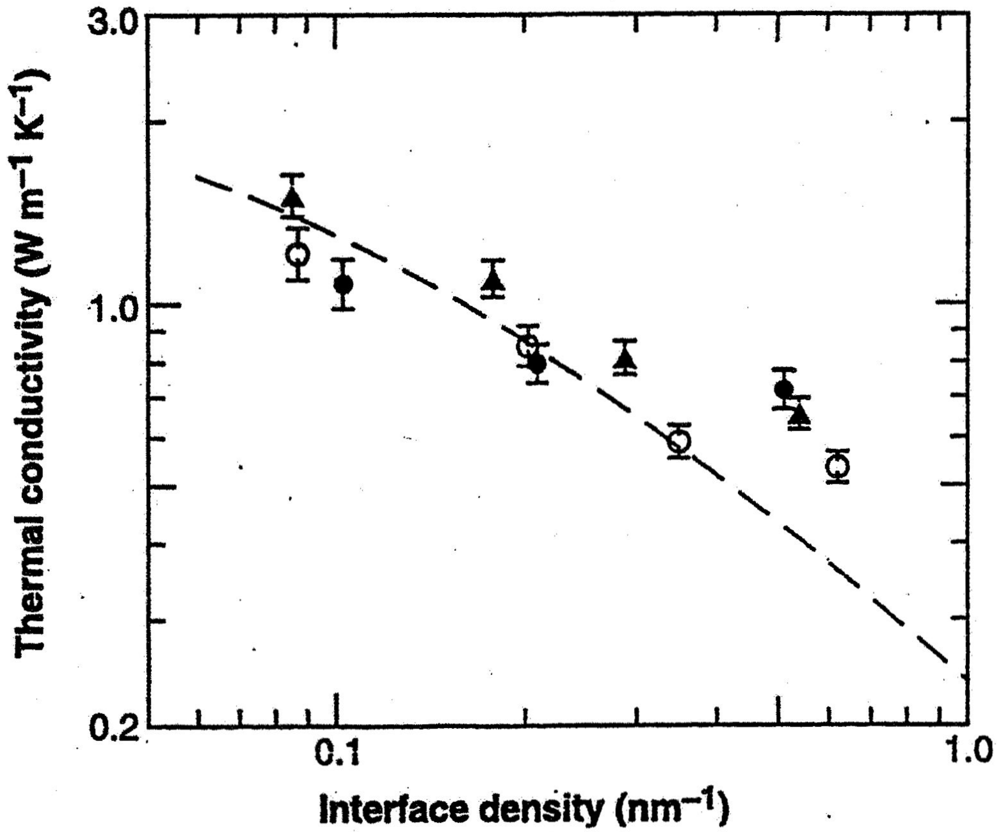
Hardness can be increased when the layer thickness is less than the dislocation length for the slip plan motion that characterizes the response of the material to stress



Ultimate tensile strength vs. copper layer thickness for 90Ni/10Cu layered composites. [D. Tench, J. White, *Metall Trans. A* 15 (1984) 2039.]

Ultra-Low Thermal Conductivity

Thermal conductivity decreases when the layer thickness becomes less than the mean free path of the phonon that transfers the heat



Thermal conductivity of W/A$_{l2}$O$_3$ nanolaminates as function of interface density [R. M. Costescu et. al, *Science* 303 (2004) 989.]

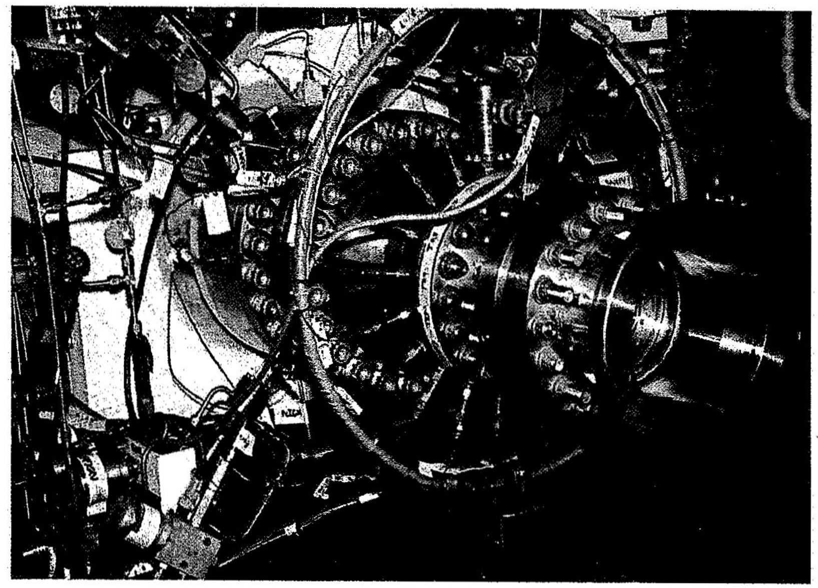
Potential Nanolaminate Applications

- Can be used wherever strength, oxidation resistance or prevention of hydrogen embrittlement at high temperatures are required

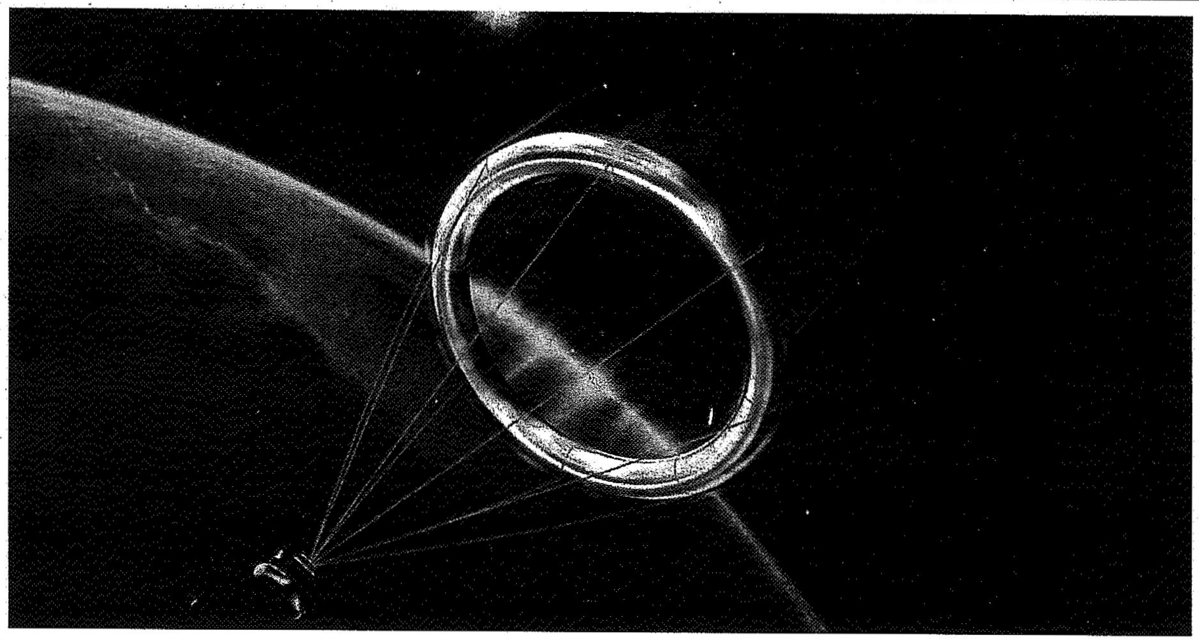
- Rocket engine components: injector faceplates, bodies and preburners

- Thermal barrier coatings to protect turbine engine blades

- Nuclear thermal propulsion systems: coatings to prevent hydrogen embrittlement
  - alumina (Al_2O_3) is a natural barrier for hydrogen diffusion; a nanolaminate can have thousands of such layers



Potential Nanolaminate Applications (cont.)



- Coating on a ballute structure for aerocapture in planetary atmospheres
- Nanolaminate coatings can have very low thermal conductivity
  - heat conduction across the layers can be lower than along the layers

Development of a Novel Ni/Al_2O_3 Nanolaminate

Objective

The objective of the project is to manufacture novel Ni/Al_2O_3 nanolaminates for propulsion applications and compare their thermo-mechanical properties to Ni alloys and Ni/Al_2O_3 metal-matrix composites (MMC)s.

Specific Goals

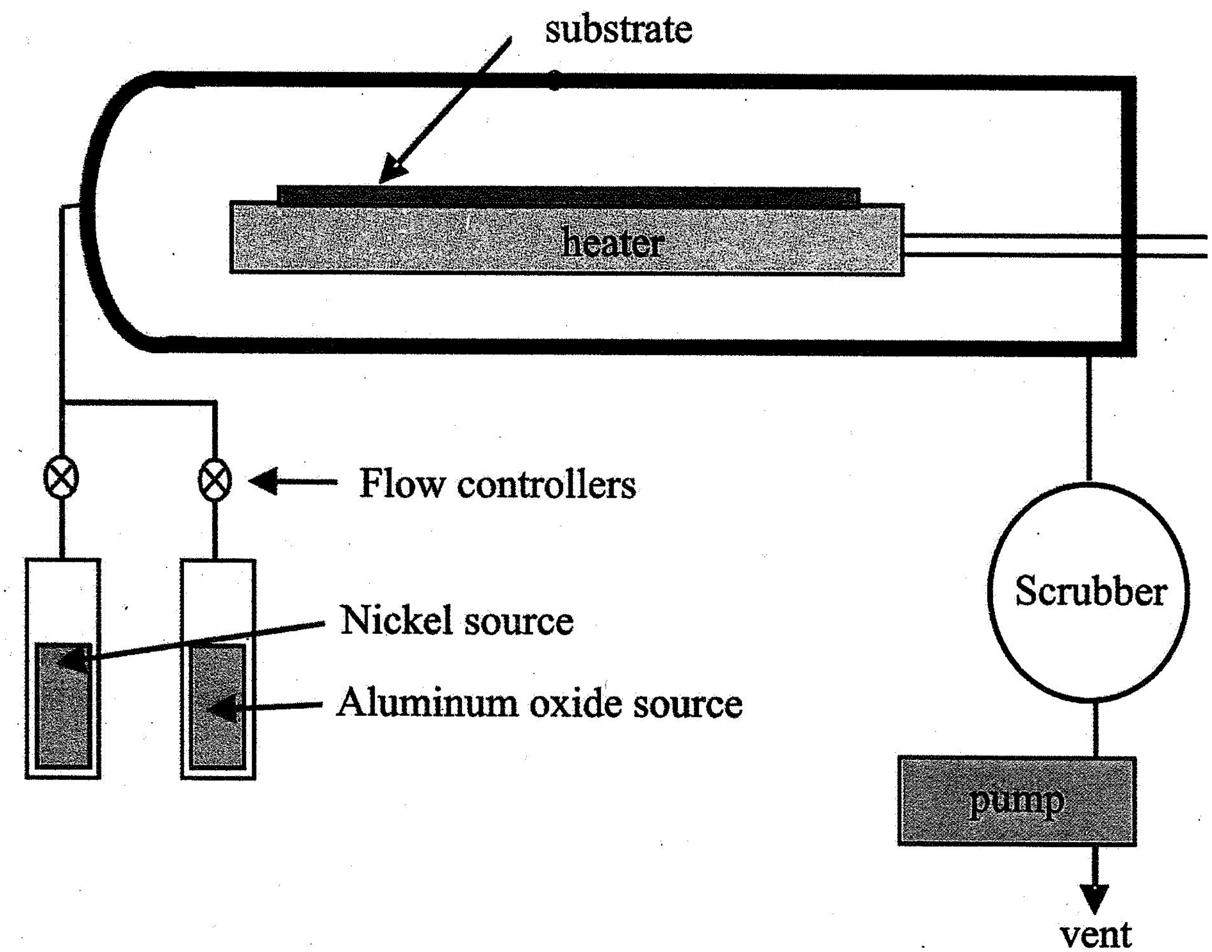
- Manufacture Ni/Al_2O_3 nanolaminates by a CVD process in rectangular structures with bilayer thicknesses of 10, 20, 50, and 100 nanometers
- Characterize the films by XRD, SEM, AFM, optical microscopy and other techniques as required to determine the bilayer thickness and structure
- Manufacture several thicker (up to 1 mm) structures for mechanical testing

Chemical Vapor Deposition (CVD) System

Low pressure CVD apparatus
- excellent uniformity
- high purity films
- good step coverage

Cold wall reactor

Liquid reactant sources



CVD Apparatus